Western North Pacific Tropical Cyclone Formation and Structure Change in TCS-08 and TCS-08 Field Experiment Support

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LONG-TERM GOALS

The long-term goal of this project is to develop a better understanding of mesoscale and synoptic-scale processes associated with the entire life cycle of tropical cyclones in the western North Pacific. The inability to correctly identify tropical cyclone formation over the period of 24 h – 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, once a tropical cyclone has formed the predictability of structure changes during intensification of tropical cyclones is very low, which is due to complex physical processes that vary over a wide range of space and time scales. Periods of reduced predictability occur throughout the tropical cyclone life cycle, which includes the decaying stage. Because decaying tropical cyclones often transition to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to an extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns that potentially impact maritime and shore-based facilities.

OBJECTIVES

A primary objective is to increase understanding of the formation of a tropical cyclone from what may have been a disorganized area of deep convection or a weak pre-existing cyclonic disturbance. Over the monsoon environment of the tropical western North Pacific, pre-tropical cyclone disturbances range from low-level waves in the easterlies to large monsoon depressions. An objective of this project is to define factors that impact the large-scale atmospheric and oceanic controls on tropical cyclone formation.

A long-term goal is to understand the relative role(s) of mesoscale processes in organizing a pre-tropical cyclone disturbance such that it may begin to intensify as a tropical cyclone. A specific

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14. ABSTRACT
The long-term goal of this project is to develop a better understanding of mesoscale and synoptic-scale processes associated with the entire life cycle of tropical cyclones in the western North Pacific. The inability to correctly identify tropical cyclone formation over the period of 24 h ? 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, once a tropical cyclone has formed the predictability of structure changes during intensification of tropical cyclones is very low, which is due to complex physical processes that vary over a wide range of space and time scales. Periods of reduced predictability occur throughout the tropical cyclone life cycle, which includes the decaying stage. Because decaying tropical cyclones often transition to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to an extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns that potentially impact maritime and shore-based facilities

15. SUBJECT TERMS

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objective is to examine processes that define relative contributions of low-level vorticity in deep convective towers versus mid-level circulations embedded in stratiform regions of mature mesoscale convective systems. This objective addresses the predictability associated with the location, timing, and rate of tropical cyclone formation over the western North Pacific.

Additional objectives address the characteristic structure changes as a tropical cyclone intensifies and then proceeds into extratropical transition. A particular focus is identification of key structural characteristics that limit the predictability of recurvature and the start of the extratropical transition process.

Finally, an important objective is define representative wind distributions and maximum intensities of tropical cyclones from *in situ* data obtained at times coincident with satellite overpasses. The purpose of this objective is to assess the ability to define important tropical cyclone structural characteristics via remotely-sensed observations.

APPROACH

Operational global model forecasts of tropical cyclone formation are routinely available. However, the objective determination of skill associated with these forecasts for various lead times, locations, and environmental conditions are restricted due to the difficulty in identifying candidate tropical circulation systems that may become tropical cyclones. Therefore, forecasts of tropical vortices made by the National Centers for Environmental Prediction Global Forecast System (GFS), the United States Navy Operational Global Atmospheric Prediction System (NOGAPS), and the United Kingdom Meteorological Office Global Model (UKMO) are analyzed with respect to physical quantities that are relevant to tropical cyclone formation.

Two primary hypotheses have been advanced for the role of the MCSs and their associated mesoscale convective vortices (MCVs) in tropical cyclone formation. The “top-down hypothesis” is that only the MCS/MCV that forms in the middle of a monsoon depression, where minimum vertical wind shear and a warm, moist, cyclonic vorticity environment exists, is able to become the point about which the central convection is concentrated to form the tropical cyclone. Once the region of central convection has been established, the vortex is able to organize via mechanisms associated with the strong updrafts that induce a secondary circulation that increases the tangential winds.

The key elements of the “bottom-up hypothesis” are that strong, deep convection in a favorable cyclonic vorticity environment creates multiple lower-tropospheric cyclonic vortices that merge to create a progressively more intense vortex that builds upward. The latent heat release in this intense vortex leads to a secondary circulation that can spin-up the vortex into a warm-core tropical cyclone with maximum winds in the lower troposphere.

The key to understanding the physical processes by which a MCS/MCV can form a tropical cyclone is to observe and model the horizontal and vertical distribution of latent heating. That is, the vertical distribution of latent heating associated with both the convective portion and stratiform portions of the MCS is a critical component. The combined observation-modeling approach is to be followed based on observations from the Tropical Cyclone Structure-08 (TCS-08) field program and collaboration with scientists at the Naval Research Laboratory and the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). The TRMM Precipitation Radar and Microwave Imager observations have been collected for the developing and non-developing pre-tropical cyclone disturbances during

the 2007 TCS-08 dry run and the 2008 TCS-08 observation period. The vertical profile of latent heating from these products will be compared with profiles from the NRL P-3 ELDORA observations in selected cases during TCS-08

The poleward movement and extratropical transition (ET) of a tropical cyclone initiates complex structural changes in the wind distribution and forcing of extreme ocean wave activity, which often lead to reduced skill from operationally produced numerical forecasts. Although these extreme conditions severely impact the region of the ET, there are significant impacts downstream of the ET event due to the excitation of large-scale propagating Rossby wave-like disturbances. The approach to the primary scientific issues associated with ET and downstream impacts due to ET events is to define a framework of mechanisms, predictability, and strategies for increasing predictability. The approach is to investigate the roles of environmental factors during ET on structural changes responsible for the generation, intensification, and propagation of Rossby wave-like disturbances that often form during ET events.

WORK COMPLETED

A diagnostic analysis of forecasts of tropical cyclone formation from operational global models was defined and implemented (Elsberry et al. 2009a). Also, the skill of 32-day forecasts of tropical cyclone events from the 51-member ensemble prediction system of European Center for Medium-range Weather Forecasts (ECMWF) was assessed during the period of 5 June through 25 December 2008 (Elsberry et al. 2009b). Analysis of COAMPS-TC forecasts of tropical cyclones that occurred during the TCS-08 field program was completed (Hensley 2009).

The structural evolution of Typhoon (TY) Sinlaku during TCS-08 has been examined as it weakened under extreme vertical wind shear then re-intensified to typhoon intensity (Sanabia and Harr 2009) prior to undergoing extratropical transition. The downstream impact of the extratropical transition of TY Sinlaku on operational global model forecasts (Sanabia and Harr 2009) was investigated using a local eddy kinetic energy budget as defined by Harr and Dea (2009). The impact of aircraft observations on the definition of the surface wind field associated with the typhoons that occurred during TCS-08 was assessed relative to remotely-sensed data (Havel 2009). The analysis of experiments that related sensitivity of forecasts of the extratropical transition of TY Tokage to data distribution was conducted (Anwender et al. 2009). The large-scale circulation over the tropical and midlatitude North Pacific region during TCS-08 was examined as an anomalous period of reduced monsoon activity by Trevino (2009). Finally, a workshop was conducted to provide principal investigators information on the data management associated with TCS-08.

RESULTS

Forecasts from four operational numerical global forecast models were examined to assess their ability to determine whether tropical cloud clusters that occurred during TCS-08 would intensify into a tropical depression (Elsberry et al. 2009a). When all four models were in agreement, the formation of a tropical depressions was likely and high confidence could be assigned to the forecasts. Furthermore, the four-model consensus had a small number of false alarms while the false alarm rate increased with a three-model consensus.

The 51-member ECMWF 32-day forecasts provided useful long-range guidance on the formations and tracks of the strongest typhoons during the peak of the tropical cyclone season over the western North

Pacific (Elsberry et al. 2009b). However, early season and late season storms were not predicted by the ensemble forecasts. The ability of the 32-day ensemble prediction to identify the period of enhanced tropical cyclone activity in September 2008 was investigated. The Week-4 forecast initiated on 14 August 2008, (about a month before TY Sinlaku struck Taiwan) resulted in a 10-member ensemble storm 21 and 6-member ensemble storm 30 (Fig. 1). As 16 of 51 members (i.e., 31%) indicated the formation of a storm with track characteristics similar to TY Sinlaku, this case indicates some intraseasonal predictability, at least for the strong TY Sinlaku.

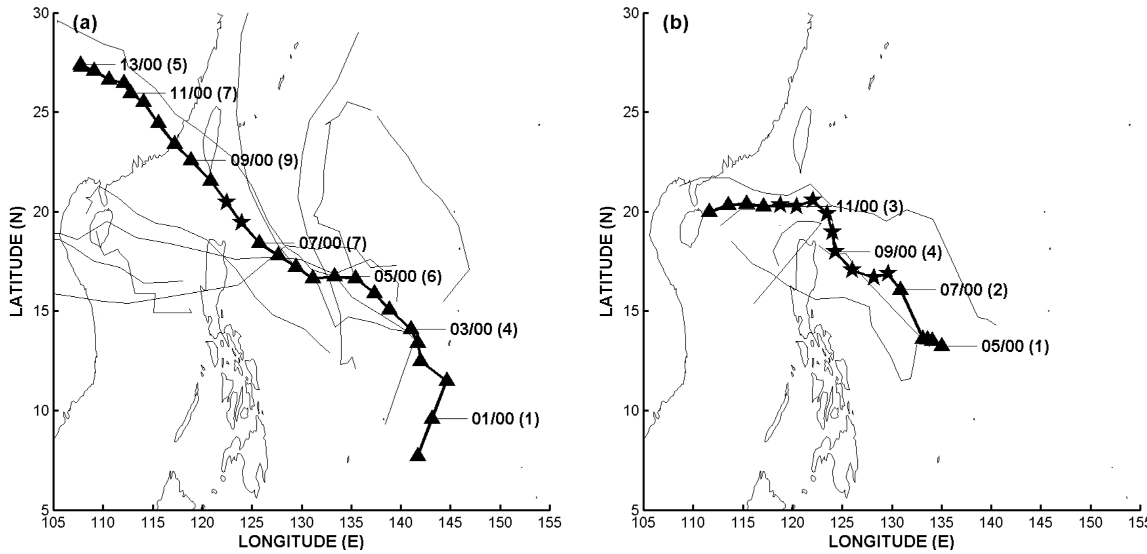

Fig. 1 (a) Ensemble storm 21 with 10 members and (b) ensemble storm 30 with 6 members in the forecast of 4-week forecast from 14 August 2008, which relates to the formation and track of TY Sinlaku during TCS-08.

During TCS-08, TY Sinlaku was a category four typhoon that passed just to the north of Taiwan and recurved. Following recurvature, TY Sinlaku became under the influence of strong vertical wind shear and weakened significantly (Fig. 2a). However, deep convection was re-initiated on the downshear side of the storm (Fig. 2b) and the storm re-intensified to typhoon strength (Fig. 2c). The ELDORA radar sampled the deep convection (Fig. 3a) and the radar-relative winds (Fig. 3b) define low-level convergence and upper-level divergence in the environment of the deep convection. Initial results also define a compact horizontal circulation at approximately 5 km (Fig. 3c).

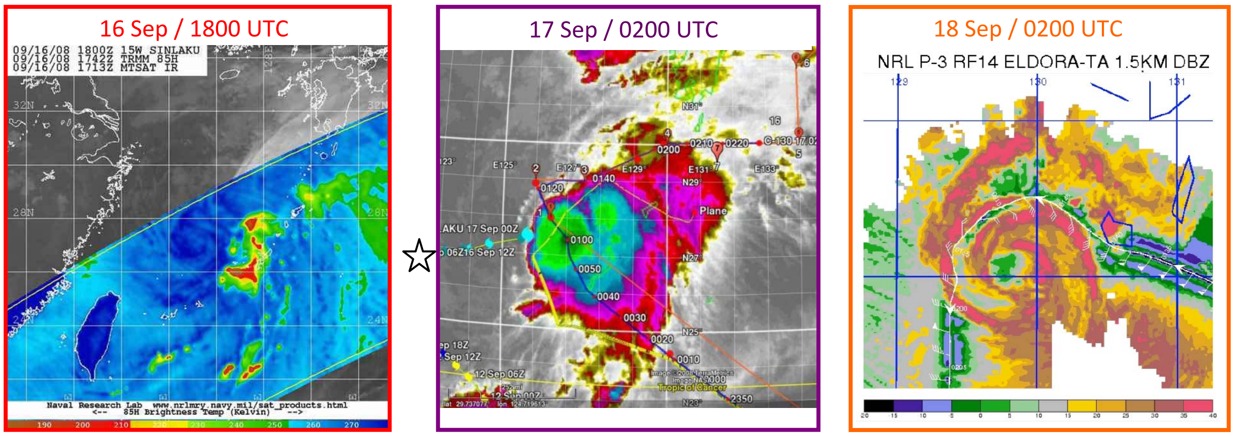

Fig. 2 (a) Microwave imagery at 85 GHz from the TRMM satellite overlaid on MTSAT infrared image at 1800 UTC 16 September 2008. (b) Color-enhanced infrared imagery from MTSAT at 0200 UTC 17 September. The blue line defines the flight track of the WC-130J aircraft. Red dots define the locations of dropsondes. The yellow line defines the flight track of the NRL P-3 aircraft. The white star defines the location of the radar reflectivity in Figs. 3a,b. (c) Composite reflectivity (DBZ) from the ELDORA radar at 0200 UTC 18 September. The imagery in (a) is from http://www.nrlmry.navy.mil/sat_products.html.

The eventual re-intensification of TY Sinlaku occurred in the region of the circulation identified by the ELDORA radar data. These results are being investigated further to define whether the circulation in the ELDORA data is a new center that developed in the deep convection or the tilted extension of the original TY Sinlaku. If the circulation is a new center that developed in the deep convection downshear of the remnants of Sinlaku, then the excellent coverage of radar, aircraft, and satellite data will lend insights as to the origin of the circulation and evolution to a new tropical cyclone.

The complexity of the post-recurvature weakening and subsequent re-intensification of TY Sinlaku impacted forecasts from operational global forecast models. The track forecasts from the NOGAPS and GFS models (Fig. 4), were consistently poleward of the analyzed storm track, which corresponded to forecasts of an extreme extratropical transition event that did not occur. Similar characteristics were identified for the ECMWF model (not shown). Errors in the extratropical transition and subsequent downstream development across the North Pacific have been linked to forecast errors associated with the sequence of weakening and re-intensification as defined above.

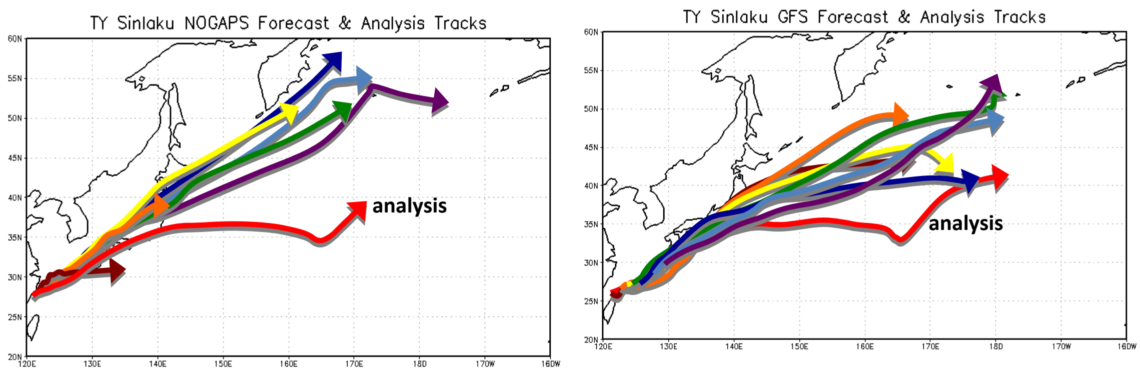

Fig. 4 Forecast tracks of TY Sinlaku from (left) NOGAPS and from (right) the GFS global models. Colors represent tracks from forecast that were initialized between 0000 UTC 15 September through 0000 UTC 18 September in 12 h increments.

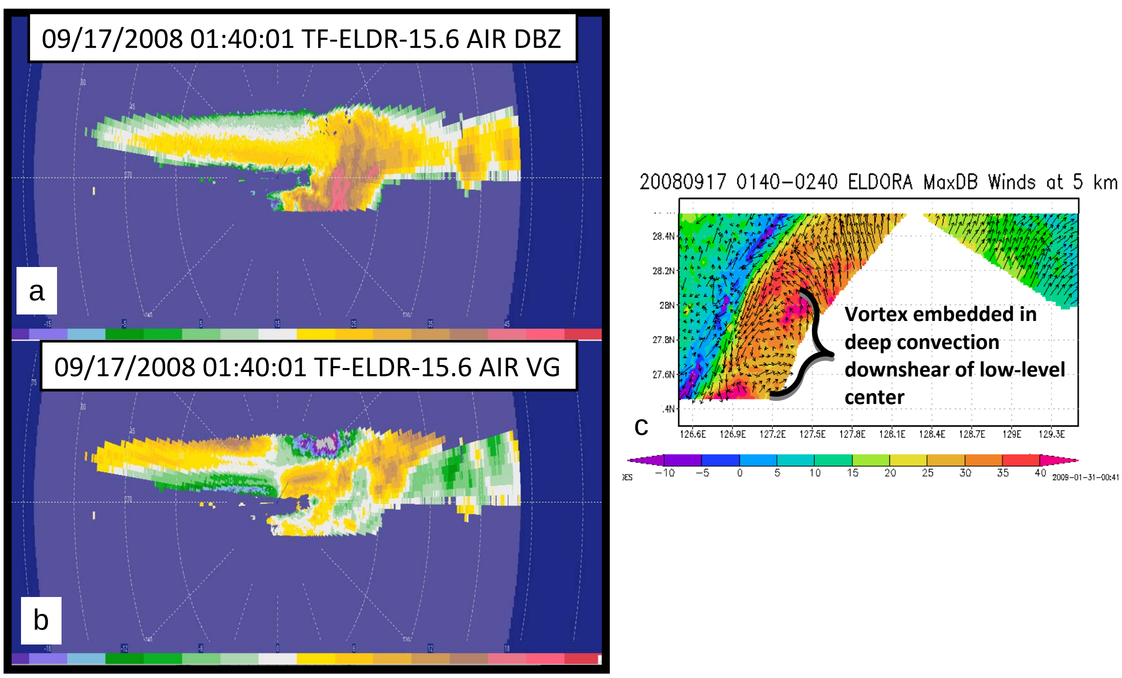

Fig. 3 (a) Reflectivity (DBZ) from the ELDORA forward-looking radar at the position defined by the white star in Fig. 2b. (b) Radar relative winds (m s^{-1}) that correspond to the reflectivity in panel a. Warm colors define winds directed from the radar and cool colors define winds directed toward the radar. (c) Horizontal winds (m s^{-1}) and radar reflectivity at 5 km defined from the Doppler radar data

Havel (2009) examined the relationship between surface winds from the stepped frequency microwave radiometer (SFMR) data on board the WC-130J and flight-level winds from WC-130J missions into

the various stages of TY Nuri, TY Sinlaku, and TY Jangmi during TCS-08. Havel (2009) also compared approximately 100 pairs of SFMR-derived surface winds to dropsonde winds to conclude that there was a slight positive bias in the SFMR-derived wind speeds and that this bias is consistent with values found from SFMR data gathered in Atlantic hurricanes. Also, Havel (2009) analyzed the distribution of maximum flight-level and surface winds and concluded that the average eyewall slope in the limited sample of typhoons during TCS-08 was slightly larger than the slope identified from a large data set of Atlantic hurricanes. The analysis by Havel (2009) is a fundamental step in identifying the basic characteristics of the aircraft data as their statistics compare to those based on a much larger sample gathered in hurricanes over the North Atlantic.

IMPACT/APPLICATIONS

The research being conducted on the comprehensive data sets gathered during the TCS-08 field program will result in increased accuracy associated with the prediction of tropical cyclone formation, intensification, and structural changes.

TRANSITIONS

Following the compilation and analysis of the wide range of TCS-08 data sets, research results that identify factors responsible for the variability in tropical cyclone formation, intensification, and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific.

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